Forensic Report
April 27, 2012

File: Nossar vs GM – 2005 Chevrolet Trailblazer

Subject: Vehicle Crash Performance

Background:

This report addresses a collision that occurred on February 25, 2010 around 3:35 pm, in Franklin County, Georgia. From the police report, James Nossar was driving a 2005 Chevrolet Trailblazer SUV on Interstate 85 when he was unable to stop for slowing traffic and impacted the rear of a 1999 Chevrolet Suburban SUV driven by Julie Dalen. This was a classic bumper underride condition. Subsequently, Mr. Nossar's Trailblazer then spun into the median after the collision.

The front airbags in the 2005 Chevrolet Trailblazer failed to deploy in this high severity offset frontal, vehicle-to-vehicle underride type collision. Mr. Nossar was a properly seat belted and properly positioned driver in the Trailblazer. As a result of the failure to deploy the driver frontal impact airbags, Mr. Nossar received severe and permanent injuries.

Material Reviewed:

- Georgia Motor Vehicle Accident Report
- Mitchell CRS Database Information for 2005 Chevrolet Trailblazer
- IIHS Crash Testing Report for 2005 Chevrolet Trailblazer
- NHTSA Crash Testing Reports for 2005 Chevrolet Trailblazer
- Inspection Photographs of 2005 Chevrolet Trailblazer
- November 2011 Inspection of Subject Vehicle
- Petition Original
- NHTSA Safety Recall Database
- NHTSA Office of Defect Investigation Database

PLAINTIFF'S EXHIBIT
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- NHTSA Consumer Complaints Database
- GM Responses to Interrogatories
- GM Responses to request for production
- SDM Hexadecimal Data Listing from Kimbro download
- GM Document Production
- GM Crash Test reports and videos
- GM Specifications
- GM Part Drawings

Examination:

This subject accident is an offset, vehicle-to-vehicle type event commonly evaluated and tested by General Motors, Chevrolet and other manufacturers as part of their standard crash testing. Using deformable barrier faces in the laboratory, similar to the IIHS Offset Deformable Barrier test, it is common to evaluate the system performance in this type of event. Offset, vehicle-to-vehicle underride conditions are common when a vehicle collides with another vehicle in a T-bone side impact intersection collision or when a vehicle impacts the rear or front of another vehicle in its path. In this case the frontal impact into the passenger side rear bumper of the 1999 Chevrolet Suburban Pickup Truck is not only severe, but extremely harmful due to the potential structural deformation which has been observed in similar testing by the Insurance Institute for Highway Safety (IIHS). The resulting crash was very severe and subjected Mr. Nossar to severe G forces without the protection of a frontal impact airbag. These G forces in turn pushed him forward towards the steering wheel and instrument panel. The resultant contact forces when he impacts these interior structures result in the injuries suffered.

GM is well aware of the significance of underride crashes to the performance and stability of crash sensing systems, and typically performs these types of crash tests to evaluate both the performance of the crash sensing system and the survivability of the crash sensing systems, to insure specifically that the crush zone sensors and wiring harnesses survive long enough to complete their task of sending crash severity information to the SDM-DS Airbag Control Module

located in the passenger compartment.

As mentioned, in the subject crash, which was very similar to the IIHS 40mph 40% Offset Deformable Barrier crash test, the vehicle sustained substantial occupant compartment intrusion. This occupant compartment intrusion was also noted in the IIHS collision and was one of the reasons the vehicle was degraded to an "Acceptable" rating from the highest possible rating of "Good". General Motors performed Offset Deformable barrier testing as part of its design and development testing plan, and would have been readily aware of this deficiency in vehicle structure performance. However, in the case of the IIHS and most of the General Motors testing, the frontal impact airbags deployed, which reduced the overall harm to the driver occupant, even in the presence of such structural collapse and deformation.

However, according to GM, there was a wiring problem in this GMs own crash test, a 40mph ODB test number C14592, and the frontal impact airbags and pretensioners failed to deploy. The resulting injury levels, as measured by the crash dummy were well above biomechanical reference levels for severe injuries. The HIC (Head Injury Criteria) reached 2370, which is well above the GM standard of 700 and the FMVSS208 standard of 1000! Chest injury and leg injury levels reached the higher FMVSS208 levels for severe injury potential as well. Clearly, from this test that GM Performed, failure to deploy the airbags and activate the seatbelt pretensioners in this severe collision can result in catastrophic increases in injury potential for the occupants.

In another GM run ODB Crash, C14272, the chest compression and G levels seen by the driver occupant were again, right at the limit of the injury values deemed to be the threshold for serious injury. This was with the airbag. Thus, the result above in crash C14592 when the airbag did not deploy, is not surprising. This gives us a great example of how catastrophic the non-deployment of the airbags can be in these severe frontal, field relevant, real world impacts, and gives us a sense of the forces which Mr. Nossar was subjected to in the subject collision.

There are other similar examples of the above occupant injury performance in the ODB tests, but another crash that GM performed that stood out as being suspect was the 30mph Pole Impact, C13245. In this crash, instead of letting the

airbags be deployed by the SDM directly, they remotely deployed the airbags. This, in itself, is not a problem, this is common to insure a reliable deployment while still verifying the performance of the SDM by monitoring its output, while not risking a non-deployment, since Occupant Biomechanical engineers are relying on this test for occupant performance numbers as well. However, what is disturbing is that the deployment is commanded remotely at 22ms after bumper contact. The actual SDM monitored deployment time is 43ms. I have NEVER seen a pole impact trigger time reliably occur at 22ms. The 43ms is more appropriate. However, even with a 22ms trigger time, the Chest injuries reached the critical levels and leg injuries were substantially close to the severe levels as well. What concerns me is that there were no other Pole Impact tests supplied in the document production and therefore, possibly no crash tests with a normal 43ms trigger time. What would happen to the already high injury levels if the system were tested with a later deployment time.

The 2005 Chevrolet Trailblazer should have been developed and tested by General Motors for expected real world crash conditions, including Offset, underride and vehicle-to-vehicle type impacts. From my inspection of the subject vehicle, it is apparent that all these conditions were present in the collision and would have been considered field relevant and highly probably crash conditions for this vehicle. If the frontal impact airbags and seatbelt pretensioners had deployed properly in this crash, Mr. Nossar would have been provided all the potential protection that was designed in to this 2005 Chevrolet SUV. However, without these additional restraints, the result was significant permanent injuries due to blunt force trauma when Mr. Nossar impacted the vehicle interior. Exactly the type of injuries that airbags and seatbelts are designed to reduce or mitigate in severe crashes.

Other vehicle manufacturers, as well as other vehicle platforms within General Motors, successfully met the safety regulations for the 2005 Model year while still providing robust and predictable real-world crash performance outside of the laboratory. Reviewing the calibration performance results, Although this vehicle meets the federal guidelines for crash safety, due to failures in the crash sensor calibration settings for the 2005 Chevrolet Trailblazer, the system is defective by design and has the potential to not deploy frontal impact airbags in high speed frontal impacts where conditions vary slightly from the perfect

laboratory conditions where the system was designed and tested. This is an unacceptable condition.

From the data reviewed at this time, it is apparent General Motors was having difficulties with this type of crash, based on the IIHS test performance. Even with a frontal impact airbag deployment in the IIHS test, the overall performance of the 2005 Chevrolet Trailblazer achieves only an "acceptable" rating, compared to the highest rating of "Good". One can imagine the performance rating if the frontal impact airbag failed to deploy, as occurred in the subject collision. Their own testing confirms this worst case fear.

Although some of the key documents have not yet been produced, we expect to identify emails and other correspondence between GM Truck Engineers and Delphi Crash Sensor engineers discussing the concerns over GM Truck Groups' edict to set certain crash sensor calibration parameters outside the recommended minimum guidelines set by the crash sensing algorithm designers. The concern was that in longer duration, but high severity events and in concatenated events (such as a curb impact followed by a utility pole impact), the airbags would fail to deploy because the algorithm deployment thresholds were no longer active.

Additionally, the dual front EFS sensor design strategy is a good one, if employed correctly. If the sensor in the crush zone is protected long enough to insure that it can send critical crash severity information to the SDM-DS before the sensor and/or wiring are destroyed (see "Sensor Mounting Guidelines Document", Section 2.6; Exhibit 2)

The failure by GM to understand the risks of certain dictated calibration values led directly to the design defect that rendered the frontal impact airbag system in the 2005 Chevrolet Trailblazer defective and unreasonably dangerous in certain field relevant, real-world crashes.

<u>Analysis:</u>

To analyze the root cause of the defective performance, we can take each possible root cause, one by one, and analyze the likelihood of the subject crash failure.

- Design Defect:
  - Crash sensing algorithm and calibration threshold settings
    - GM has not yet provided specifications and other production documents for review in this area, however, I have seen these documents before and know the content.
    - In reviewing the crash performance of the sensing system for the subject vehicle, with respect to the conditions of the subject crash, it is clear that the calibration values result in premature turning off of algorithm thresholds which effectively disables the front airbags after 45 to 50ms.
    - Additionally, although the SDM-DS single point sensing calibration in the passenger compartment is not generally effective near threshold conditions for a body-on-frame truck platform, it can be utilized as a redundant sensor in high speed frontal impacts, such as the subject accident.
    - Pending discovery responses from GM disclosing calibration details including computer simulated performance, calibration parameter files and actual crash test performance of the SDM-DS calibration, I expect to prove that the SDM-DS was NOT calibrated to provide high severity redundancy, and is thus, defective in addition to the EFS (Electronic Front Sensor) discussion below.

  - Design, Placement and Protection of the EFS Devices:
    - From the vehicle inspection and my knowledge of this vehicle design, there was no obvious design defect in the placement of the crash sensors in the system.
    - However, the routing and location of the crash sensor wiring harnesses is suspect.
    - The fundamental requirements for crush zone sensor placement and protection, as outlined in the Crash Sensor Mounting Guidelines Document (see "Sensor Mounting Guidelines Document", Section 2.6; Exhibit 2) was not adhered to, resulting in the potential to lose front crash sensor integrity and

function prior to being able to send critical crash severity information to the SDM-DS.

- Component Failure or Other System Defect:
  - Failure of the Electronic Front Sensors
    - Component failures in airbag systems are generally very rare.
    - Additionally diagnostics in place are usually highly reliable at detecting faults and illuminating the airbag warning lamp that a potential defect exists.
    - There is nothing at this time, based on any documents or information provided, that would lead to the conclusion that the EFS device had failed in the days, weeks or months prior to the subject crash, leaving a warning lamp illuminated.
    - As stated above, although not a failure of the sensor due to internal component failure, but external damage and loss of connectivity of both front sensors, potentially due to defective routing of both EFS wiring harnesses to a single point behind the Driver Side EFS, results in a single point defect, if the crush of the vehicle structure impinges that location where both sensor wires are routed together, while still in the crush zone of the vehicle, as opposed to being routed separately and independently to insure a single point of damage cannot wipe out both sensors simultaneously.

  - An SDM controller internal failure:
    - The SDM could not receive or interpret EFS incoming crash data.
    - The SDM received EFS crash data but incorrectly processed the severity of the crash
    - The SDM received the EFS data, commanded a deployment of the frontal impact airbags, but another fault condition prevented the airbags from deploying.
    - However, since the SDM was downloaded by disconnecting the harness from the SDM, without proper representation by both

parties and the use of a proper SDM Event Data Recorder download protocol, there is a concern for spoliation of evidence in this case. Once the connection is broken, a failure of a component or connection is no longer diagnosable.

Failure of the SDM calibration is the most probable reason for the failure to deploy in the subject collision. Additionally, based on the generally assumed component and diagnostic systems, it would be highly unusual that a fault condition existed prior to the subject collision, leaving an airbag warning lamp illuminated on the dashboard. If the EFS's are wiped out early in this subject crash event before they can perform their crash sensing function completely, we have the first defect in the system design. Subsequently, if the SDM-DS calibration is not providing a redundant crash sensing function in high severity crashes, we have uncovered the second defect in the system design.

Both design defects are necessary to result in the catastrophic injuries suffered by Mr. Nossar as a result of the failure to deploy the airbags in this high severity, field relevant, real world collision.

The likely SDM failure occurred during the crash, when the EFS devices failed to provide their critical high severity crash indication due to premature sensor/wire harness damage, and after the SDM calibration had already timed out after 45-50ms after the crash started. By not calibrating the SDM-DS algorithm/calibration for necessary redundancy, and failing to properly protect the sensors and wiring of the front crush zone sensors, the complete failure of the crash sensing system for airbag deployment resulted.

Although SDM and EFS internal fault conditions prior to the subject collision cannot be completely ruled out, there is no evidence from any documents provided that Mr. Nossar had seen the airbag lamp illuminated prior to the subject collision. These types of failures are highly improbable anyway, with today's highly reliable electronics and diagnostics, but always need to be considered.

If any further documentation regarding the life history of the subject vehicle or details of field returns and defect investigations, should indicate that this type of

failure may have been prevalent on this vehicle platform, then additional research will be provided, likely in joint inspections and teardowns, to identify possible internal sensor system failures. That is not deemed necessary at this time, based on the facts of this case.

It is quite clear that GM has a serious risk of injury in an offset, vehicle-to-vehicle type collision, if the airbags and seatbelt pretensioners do not deploy. Although key documents have not been provided regarding the calibration of the SDM-DS and EFS sensors at this time, my experience leads me to a conclusion with a high confidence that the SDM did not deploy the airbags in the subject crash because the time duration was slightly longer and initially softer than the ODB type collisions tested, which typically had a crash pulse time duration of more than 135 milliseconds (ms). The system failed to recognize the severity of the crash before the EFS wiring was damaged and failed to provide an airbag to protect the occupant when the SDM-DS failed to have a redundant capability to supplement the EFS performance in such cases. This performance is obviously defective and unreasonably dangerous for the occupants of a 2005 Chevrolet Trailblazer.

The circumstances of this crash event lend themselves to a conclusion with a high degree of engineering certainty that the 2005 Chevrolet Trailblazer Truck was defective and unreasonably dangerous in the subject collision due to the design defect present in the frontal impact, ALGO-S-G crash sensing calibration parameters as well as the location and routing of the EFS crush zone sensors and wiring.

Opinions:

Based on the review of all the available accident information, a detailed review of the photos, reports, and based on my years of experience designing crash sensing systems and investigation crash events, it is possible to formulate the following conclusions and opinions regarding this crash.

The following opinions are offered to a high degree of engineering certainty:

- The 2005 Chevrolet Trailblazer driven by James Nossar experienced a

frontal offset, underride, vehicle-to-vehicle crash of sufficient severity for a properly seatbelted occupant to require the deployment of both stages of the dual stage frontal impact airbags.

- The 2005 Chevrolet Trailblazer driven by James Nossar experienced a frontal offset, underride vehicle-to-vehicle crash of sufficient severity for a properly seatbelted occupant to require the deployment of seatbelt pretensioners.
- The injuries sustained by James Nossar would have been significantly reduced or eliminated had the frontal impact airbags and seatbelt pretensioners deployed in this severe, highly field relevant, vehicle-to-vehicle crash event.
- The failure of the complete frontal impact crash sensing system design (including EFS sensors and wiring as well as SDM-DS redundancy calibrations) to meet the critical deployment conditions in the subject real-world field relevant collision was therefore defective and unreasonably dangerous.

These opinions are based on all data which was available at the time of this report. Additional data provided as a result of detailed document discovery and production, at a later date is likely to result in a refinement in the opinions and conclusions generated in this document.

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(CV Provided Upon Request)

DELPHI
Automotive Systems

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Document XDE-6013

EXHIBIT 2
TO FORENSIC REPORT OF CHRIS CARUSO

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03/22/00

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1.0 Introduction

The ideal Delphi Delco Electronics sensor mounting specification could be stated as follows:

> *"Three-axis transmissibility of unity gain from 0 to 1000 hertz; up to 3000G's. No degradation of mounting for 10 years and 100,000 miles. No change in mounting location vibration as a result of the mass of the sensor."*

Of course applying this specification to mechanical structures and the sensing system is no small task. It requires support of all levels of the Vehicle/RSE system teams from the structural designers and engineers, to the sensor manufacturers. It is for this reason that Delphi Delco Electronics is creating this document to help guide the development of practical guidelines for locating, mounting and servicing crash sensors.

This document is intended to be a 'living document', which will be updated as new information, data and new sensor technologies become available. Every system will be unique and every sensor may react somewhat differently in different vehicles. Structural response, resonances, location strategies, even sensing algorithms, may create unique challenges in a given vehicle structure. Thus, this document will be successful if it provides a baseline for the analysis and development of current and future vehicle systems.

This document will not provide a tool for designing a vehicle structure or interface. Each vehicle and each sensor will have unique needs and pose unique problems. This document will be a good source for learning the general strategies and concepts for optimizing the system. By understanding what is important to crash sensor performance, the vehicle designer or release engineer might be able to better specify such things as sensor location, structural performance requirements and system mechanization.

Previous updates (11/15/99) included the side impact airbag technologies, new case studies from the last 8 years, new electronic satellite sensors, and an insight into other upcoming technologies and how they will impact our crash sensor mounting philosophy and guidelines.

This update (03/22/00) includes section 3.9, where we discuss the recommended instrumentation and packaging strategy for EFS frontal sensors considering the implications of the modified FMVSS208 regulations which are currently pending approval (SNPRM).

2.0 Crash Sensor Location Selection

The crash sensor location selection is important for not only insuring adequate signal strength, but also for guarding against undesirable phenomenon, such as resonances, service abuse conditions, harsh environmental conditions, etc. Each of these areas must be carefully considered and incorporated into the final component and system design.

2.1 Crash pulse requirements for optimal sensing

The basic requirement for the structure/sensor interface is that the structure must supply a signal that can be detected and discriminated by the sensing system within the time period specified for deployment. This signal should not be contaminated by spurious signals, which could mask the primary crash pulse from the sensing system. Those spurious signals could result from the structural response, the sensor response or the interface/mounting configuration response.

First, there must be a distinguishable difference between the crash pulse from a non-deployment and a deployment level input by the customer goal time. Do not forget to include the inflation time of the airbag or other system when evaluating whether there is a discriminatible signal by the required trigger time. Some competitors have resorted to highly aggressive pattern recognition approaches to attempt to discriminate crashes where the physics does not provide a robust solution. In most cases, this will result in results that look good on paper, but ultimate field performance must be considered.

Second, it is important to maintain a monotonically decreasing (deceleration) velocity in the passenger compartment of the vehicle throughout the pulse. Sudden loss of deceleration (due to structural yielding or 'springing') may tend to 'reset' the sensors or sensing algorithm, wasting the work done by the structure and bumper system to that point in time.

More specific guidelines are difficult to express, as each sensing system will have its own unique advantages and sensitivities. But it is important to recognize that this is a 'System' and not just an add-on device. The final performance of the system will be a function of all the components of that system (vehicle, brackets, sensor, etc.) and the way they interact in the system.

2.2 Crash to crash repeatability of sensor location

When sensors are calibrated for a particular vehicle application it is assumed implicitly that the crash pulse used for each calibration decision is nominally repeatable for future similar tests. If structure in front of the sensor (relative to its sensitive axis) creates an unpredictable repeatability at the sensor location, then the sensor performance may deviate from the projected performance. Thus, it is important for Delphi Delco Electronics Applications engineers to advise the customer

when there are concerns over candidate sensor locations which may result in non-repeatability of the crash pulse signal.

An example would be when the localized structure experiences a large rotation during an even, prior to the sensor trigger time goal. If the rotation is factored into the calibration threshold selection, and then in subsequent crashes, the rotation does not occur, the sensor decision could be very different from the way it was calibrated.

Sensor design philosophy and calibration philosophy will minimize some of this risk and variability, but ultimately, the calibration is dependent on the input data accuracy and repeatability.

2.3 Symmetry of Location

Generally, when developing a crash sensing system for a vehicle, it is important to insure the system is place as symmetrically as possible in the vehicle. The crash signal differences observed due to asymmetry in the vehicle structure can create problems when dealing with such events as angle and offset impacts in frontal collisions, and with front door vs. rear door impacts in side collisions.

The goal here is to consider the effects of crashes do different parts of the vehicle structure and compensate for these theoretical events in the sensing system design and mechanization. It is important for the customer to advise the calibration engineer if there are concerns about the asymmetry of a chosen sensor location. These problems are generally compensated with a good algorithm design, but still can be dependent on the particular vehicle structure and the sensing system implementation. Just remember that symmetry is desired in the mechanization of the system.

This is also relevant when considering such items as the SDM safing for Side Impact crashes or the SDM performance in the frontal system with EFS sensors. All sensors in the system could be susceptible to degraded performance if they are not symmetrically located in the vehicle.

2.4 Mounted to structural member

The vehicle crash pulse transmissibility to the sensor is very dependent on the proximity of the sensor to a load bearing structural member. As the vehicle crushes, crash information is transmitted along the rails and into the structural cross members. As this signal is passed into the floorpan and other non-structural sections, resonances, vibrations, and other localized phenomenon can contaminate the incoming structural signal with noise. In order to minimize the variations seen by the sensors during real world crash conditions, it is advisable to have sensors attached directly to structural members such as rails, sills, tunnels, #2 bars, B-pillars, etc. This

should not only result in faster signal transmission to the sensor, but also aid in preventing undesirable localized structural characteristics from limiting the sensors effectiveness.

It is important to use a sensor location that will have minimal influence from such things as panic braking, suspension inputs, steering system inputs, etc. These non-deploy conditions should not be significant enough to influence the calibration decisions. This could jeopardize the performance during crash events where deployment is desired.

2.5 Specific location designed for sensors

Now that airbag systems are mostly standard on worldwide vehicles, it makes sense that more time should be allotted during the design phase of new vehicles for preparing the structure to accept crash sensors. For many years now, the sensors have been considered 'add-ons', which has resulted in non-optimal performance for the reasons stated above.

Specifically, the structure locations chosen should be designed for optimal crash pulse transmissibility, while also comprehending resonances and vibrations which can impede sensor performance. Additionally, it is important to specify structural members/materials that can support the mass of the sensor without creating new resonance modes which could impede the sensors performance. Every sensor technology will have unique characteristics to be considered, but in general, all sensors will perform more reliably with the basic elements of Chapter 3 taken into account.

2.6 Protection from structural rotations and damage

When specifying sensor locations on the vehicle, it is important to consider the possibility of damage to the sensor or harness during a crash event. This is particular true of satellite sensors in the side or frontal crush zones. If the sensor should fail due to damage, then it will no longer be able to provide pertinent crash information to the main controller, and this may degrade the overall system performance.

Such considerations include whether or not the vehicle structure has a tendency to rotate in the localized region, which could place the sensor in an orientation which would render it unable to detect signals in the desired axis of vehicle input. Another concern is the timing of the crash sensor damage. If the damage occurs after the sensor has done its job, then the system impact might be negligible, but if the damage occurs before the sensor is able to make its decision know to the outside world, then the system may not perform as desired.

The best scenario would be where the normal vehicle crush occurs till after the desired trigger time, and then if rotations or other failures occur, the system will likely have already satisfied its objectives successfully.

2.7 Environmental and abuse/misuse protection

The crash sensor location should also take into account the possibility of environmental or mechanical stress during its projected lifetime.

If the sensor is exposed to extreme heat or cold, fluids, service abuse conditions, road hazards, etc., then it is possible that the sensor could fail prematurely. Additionally, extreme abuse conditions could result in inadvertent actuation decisions. The sensor should be located in an environment that creates as much protection as possible to insure long life and optimal performance. Some examples of possible concerns would be having harness connectors that face up (subjected to fluids pooling up), facing into the crush zone (more likely to be destroyed before sensor completes its task), being on a floorpan which can flood readily and submerge the sensor, etc.

With environmental conditions, it is important to advise Delphi Delco Electronics engineers of any specific compatibility concerns which the sensors are expected to survive, but may be beyond the current scope of the sensor design. Delphi Delco Electronics must insure that all sensors meet the environmental compatibility requirements specified by the customers.

2.8 Serviceability

The sensing system should not need servicing for the life of the vehicle under normal operating conditions. However, experience has taught us to expect the unexpected. Therefore, anticipate that service or replacement may be required for some sensors, and it is imperative that the service procedures and labels clearly warn service personnel of the ramifications of improper installation of a crash sensor. Misorientation, missing bolts, loose bolts, wrong sensor part number, etc., can all lead to undesirable operation of the sensing system. Caution must be emphasized when working on any part of the crash sensing system.

2.9 Non-removal during other service procedures

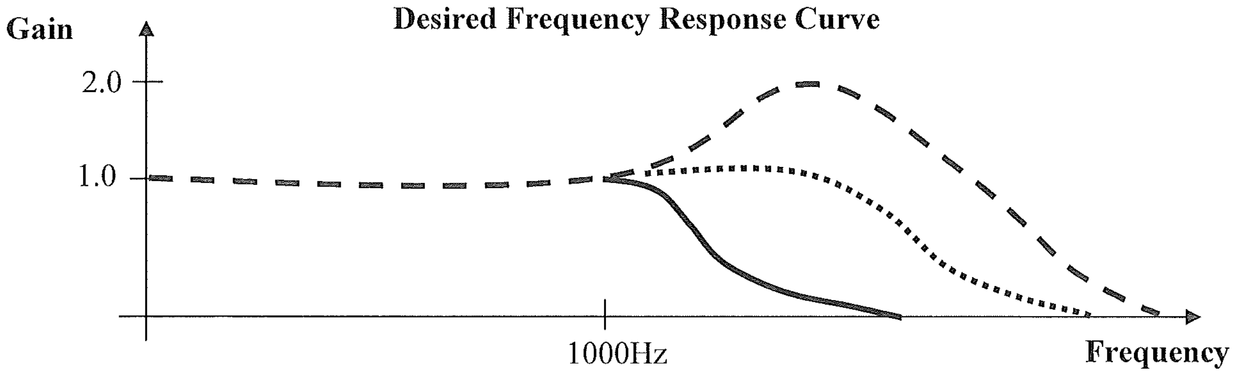
To preserve the crash sensing integrity of the system, it is important to locate sensors such that regular service and maintenance procedures (such as oils changes, belt changes, etc.) will not require removal of the sensors. The significance of improperly reinstalling a sensor can not be understated. The orientation of the sensor and the quality of the interface between the sensor/structure can be critical to the performance of the system.

3.0 Sensor/Structure Mounting Interface Guidelines

There may be sensitivities in the various crash sensor types which result from cross-axis or resonance characteristics inherent to the sensor design. Thus, it is important to design the sensor/structure interface to minimize the impact of spurious signals on sensor performance. The following topics are derived chiefly from experiences that have been gained over the last 13 years of crash testing, product validation and field performance of millions of vehicles. Additionally, each of these areas can be improved if the structural design community is aware of the sensing system sensitivities and requirements.

3.1 Resonances

The coupling of the sensor to the structure will naturally create resonant frequencies due to the mass, stiffness, torque and mounting integrity/contact surface. This resonance could impact the sensor performance if the frequencies and amplitudes of these resonances are in the sensitive region of the sensor. The specific conditions will usually be dependent on the technology used for that sensor, but in general it is best to strive for resonances to occur at higher frequencies (above 1000Hz) and with minimal gains (Q<2.0). But each sensor technology may require more or less stringent guidelines.



It is understood that the sheet metal structures of most vehicles can not be well controlled in the frequency bands above 50Hz or so, but some good rules of thumb will normally help satisfy the low gain criteria, and provide an adequate sensing environment. The following topics will help provide some guidelines for minimizing the potential for undesirable vehicle conditions.

3.2 Cross-axis inputs

Similar to resonance issues, the cross-axis issue refers to signals that propagate to the sensor from axes which are not in the sensitive direction. These 'off' axis inputs could impact the sensor performance, usually creating a desensitized condition where the crash sensor does not respond to the normal input as desired. Again, this is technology dependent, but in general, it is important to be able to quantify the structural response adequately, to properly assess the possible impact on the sensor. This is typically accomplished by collecting tri-axial acceleration data

whenever possible, during crash tests, as well as rough road/misuse and other vehicle test conditions.

In general, the cross-axis sensitivities of the particular technologies will be in the simulation models for that device, and therefore, the tri-axial data will enable Delphi Delco Electronics to quantify any possible problems with a given sensor location or configuration.

Understanding these cross-axis characteristics in the vehicle, early in the development or design phase, will be important for the final decision on sensor technology, location and mounting properties.

3.3 Crash pulse transmissibility

The crash sensor calibration process still relies heavily on the collected crash data from either FEM models or actual crash tests. The repeatability of this crash pulse shape will be a significant contributor to reliable sensor actuation in future crash tests or actual field events. If the sensor/structure interface is a weak link in the system and the crash pulse obtained during the initial signature data is not seen in subsequent testing due to a poor interface design or other localized structural phenomenon, the performance of the sensor may not be consistent.

During testing, the most reliable data is collected from test accelerometers, which are placed on the crash sensor housing, preferable near the center of mass or in line with the sensitive axis of the device. These acceleration signals should already take into account any influences from the localized structures and interface transmissibility, and therefore, will improve initial calibrations.

It is also desirable to mount an accelerometer on the structure near the sensor. This will help for comparing signal levels being transmitted by the structure to the sensor and evaluating the transmissibility characteristics of the sensor interface.

3.4 No amplification, attenuation, frequency change to crash pulse

It is desirable, as stated in 3.3, to have minimal or no perturbations to the crash pulse as a result of the interface between the sensor and structure. Any modifications in the pulse shape, level, frequency content or other pulse characteristics that were not present in the calibration crash data could result in deviations from predicted system performance.

This also applies to changes in the vehicle structure during the development process. These structural modifications, especially those which are in front of the sensitive axis of the sensor, can impact the ultimate performance of the device during crash inputs. Any deviations in crash pulse characteristics can result in similar deviations in crash sensor performance.

3.5 Cantilever bracket effects

Particularly for crush zone sensors in the doors or up in front of the vehicle, due to packaging constraints, there have been bracket designs in which the sensor ended up being suspended from a cantilever or 'diving board' extension. These types of orientations are susceptible to strong cross-axis vibrations (see section 3.2) which can have an adverse impact on sensor performance. Additionally, these designs can be quickly 'rotated' out of the proper orientation during a crash event. The mass of the sensor coupled with the center of mass can result in very large forces being applied at the mounting bolts, and this can cause a large bending moment in the structure.

This is an area where we must use good engineering judgement. These designs can be more susceptible to this type of problem, but it may not show up during the standard customer testing. We must make sure the sensor will perform properly in all foreseeable field circumstances. The sensor needs to be made an integral part of the design and not considered an 'add-on' device that can be placed anywhere that is available and always perform correctly under all conditions.

Vehicle FEM studies can be used to evaluate these issues during the design phase of the vehicle.

3.6 Interference from other structures

Primarily in the crush zone, the sensor performance is generally based on what is happening in the structures in front of it during the vehicle crash impact. If any structure in front of the sensitive axis of the sensor is changed or modified during vehicle development (like bumper changes, door shell material changes, etc.), then it is possible that the sensor performance may differ from what was originally projected. When the various structural members collapse and impact each other, the resulting information is eventually passed to the sensing system. If a component should impact the sensor location, it is highly likely that performance of the sensor will be very dependent on the characteristics of this impact. Thus, if the impact varies significantly from vehicle to vehicle or test to test, the performance of the sensor may also show variation.

The objective is to keep the sensor from being adversely affected by some structure or component prior to the desired trigger time, as this could move the sensor away from the sensitive axis prematurely, or could inhibit the sensor actuation.

3.7 3-Point mounting (stabilize all 6 degrees of freedom)

Sensor/structure interfaces can be made more stable with the incorporation of a minimum of 3 mounting points. However, as the sensors have become smaller and lighter, the need for strict 3-point mounting is reduced. But the concept is still valid, and remember that the term 3-point

mounting can refer to an actual 3 bolt/nut configuration or any method that attaches the sensor to the structure at 3 points. In the past, this has been done with such things as springclips or tabs.

Keep in mind the main objective here is to control the sensor such that all 6 possible degrees of freedom are stable, such that the input signal to the sensing mass is as close as practical to the input transmitted by the vehicle structure in all axes.

Some recent satellite sensor designs have used 2-point and even 1-point mounting with respect to the number of fasteners used. But keep in mind that these designs require being pressed against the structure, and usually have orientation locator pins that also force additional contact points to the vehicle structure. Thus, the concept of 3-point mounting refers to contact points so that the sensor is not cantilevered with respect to the bracket, but does not demand 3 physical fasteners. The lighter the mass of the part, the easier it will be to stabilize with fewer fasteners.

One point of advice would be to consider the center of mass of the device. The further the center of mass is from the mounting plane, the greater the moment of inertia will be, and the more important the fastener/mounting point design will be. We are trying to prevent the device from having large relative displacements with respect to the localized structure, as these displacements will result in significant deviations in what the internal sensing mass experiences in a crash or other vehicle situation.

3.8 Center of mass/moment of inertia mounting

One method of minimizing resonance amplitudes and shifting resonances to higher frequencies is the use of a center of gravity mounting. This is evident in the design of a recent satellite sensor package with a single mounting bolt.

The objective is to try to mount the sensor along a plane that passes through the sensor sensing mass, and ideally, this will also be near the center of mass of the device. This helps to limit the possible displacements of the device as mentioned in section 3.7. By limiting the opportunities for the sensor mass to become a significant factor in the resonance properties of the localized structure, we can improve the consistency and repeatability of the sensor performance.

FEM simulations are usually quite valuable for designing the structure interface to optimize the sensor mounting conditions. The component drawings and specs can be referenced to identify the center of gravity of the particular sensor design being used.

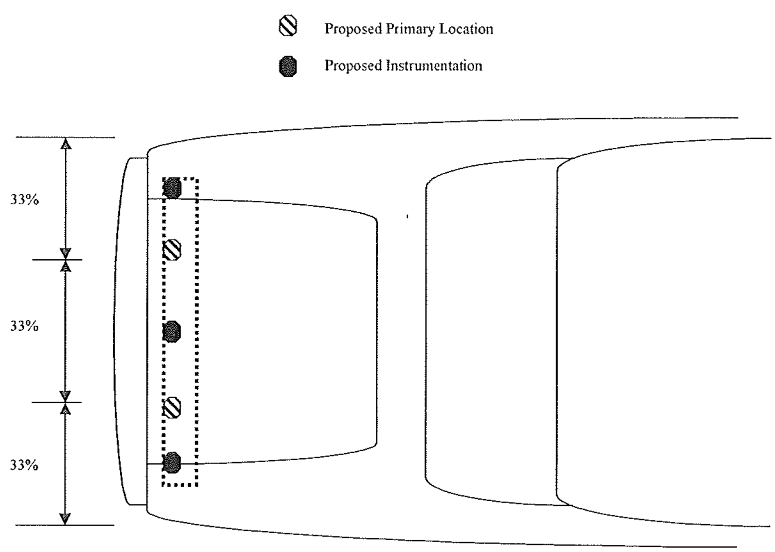
3.9 Frontal Crush Zone Sensor Location Strategy Proposal

With the modifications to FMVSS208 (frontal passive restraint legislation) passed by NHTSA, the following guidelines are proposed for optimizing the tradeoffs in requirements for Frontal sensor (EFS) applications.

When the Dual Stage systems were proposed (now called Advanced Restraint Systems) in 1996-7, Delphi stressed that protection requirements which mandated a mandatory Stage 2 deployment in conditions of high speed (>30mph) angular impacts and offset deformable barriers (ODB's) would significantly limit the capabilities of current technologies such as EFS. At that time, most OEM's felt that Stage 2 on these types of events was probably not critical, and therefore, the center radiator support locations became the primary location for sensing, to optimize for pole impact severity.

With the latest rulings, it appears across most OEM's that the Stage 2 High Speed Angle and ODB deployment is becoming a firm requirement. As such, we are proposing a new instrumentation and packaging strategy to try to balance the trade-offs between pole impacts and oblique impacts, while keeping within the physical constraints of current technologies of using a maximum of 2 front sensors (EFS).

The proposal would be to instrument up to 5 locations across the vehicle front end as shown in the following figure:



EFS Location Instrumentation Strategy

With this approach, it is anticipated that a centerline or offset pole impact would still involve the sensor locations by the needed trigger times, while allowing the sensor to enter the crush zone in a timely manner during oblique impacts, such as angle or Offset conditions.

Additionally, when considering whether to use Upper or Lower structural locations, the following must be considered. First, the bumper underride conditions for deploy/no-deploy are difficult to achieve with the lower locations, based on current evaluations. However, the upper locations tend to be more susceptible to abuse/misuse conditions such as deer impacts and hammer impacts, making calibration more difficult in these situations. Generally, we have been optimizing in passenger cars using the upper locations and the trucks tend to be moving towards the lower locations. Since underrides are less likely in current truck vehicles, this location may provide a better overall solution.

It is recommended that all OEM's consider these strategies during development testing, since inevitably, the tradeoff discussion between pole impacts and oblique impacts will arise.

3.10 Crash sensor orientation requirements

All sensors should be mounted to the vehicle with the assumption that fluid submersion, severe crash impact damage, and possible sensor design characteristics are properly considered.

A sensor should never be mounted in such a fashion where moisture or fluids can sit on the device and over time, penetrate into the operating mechanisms. Sensor sealing is a first line of defense, but continuous exposure to these conditions may eventually cause a fluid intrusion problem. A front sensor should not be oriented with the potting side facing up, for example. Constant exposure to fluid lying on the potting may eventually create a weak area and result in fluid intrusion. SDM sensors should not be placed on the floorpan without proper provisions for the eventuality of flooding. Even with potted sensor designs, constant exposure to fluids, coupled with the temperature extremes may ultimately weaken the seal.

For crush zone sensors, the connector side should never be located in front of the sensor, putting it in the path of the crushing structure. If the crushing vehicle should damage the connector early in the event, and cause sensor communication to be lost (cut wires, broken connection, etc.), then the system will not operate as designed. The goal is to get the sensor discrimination information sent out before any sensor damage can occur.

Finally, some sensor designs may not be completely symmetrical. This was more common in older electromechanical designs, but it is important to consider any unique sensor properties when designing the sensor mounting orientation. For example, an older sensor design had a clearly defined gravitational orientation. If the sensor was not mounted in this design intent

orientation, some subtle performance deviations could occur. Other designs are symmetrical in 2 axes, and therefore, the sensor can be oriented in any 360 degree rotational angle around the sensitive axis.

3.11 Structural stiffness/rigidity (N/cm)

When the sensor mass is placed on the structure of the vehicle, it can create a system resonance, which may place the sensor in an undesirable frequency band. Ideally, the structure should have stiffness properties that can support the sensor mass without experiencing a significant shift in system resonance performance.

The structural member should have a minimum stiffness which would support the appropriate sensor mass (mass varies for each technology…SDM, ADS, EFS, etc.) and maintain localized resonances and vibrations above 500 Hz minimum, with 1000 Hz the target for crush zone sensors. Since the frequencies of most interest to the sensing performance lie below these targets, this would enhance the repeatability and reliability of the system.

Additionally, the rigidity of the sensor attachment/interface should be designed so that crash signals are not significantly attenuated and non-crash inputs are not significantly amplified.

3.12 Flatness specifications

The sensor/structure interface should insure that the flatness requirements at the mounting points are met since adequate flatness can significantly reduce the resonant frequency of the system as verified in vibration testing at the component level. The problem occurs when contact surfaces are not properly mated between the sensor and structure due to flatness control. It is possible to mask this problem by increasing the torque of the fasteners, but this could potentially lead to durability problems if significant stresses are placed on the sensor bracket or structure. It is best to maintain good control of the component and mating structure flatness requirements to insure the optimal mounting interface.

3.13 Use of dash mats and sound deadeners

The interface between the sensor and structure should be a direct connection with no foreign materials contaminating the interface. Dash mats and sound deadening materials, for example, should not be sandwiched between the sensor and structure, as this could corrupt the transmissibility of the crash signal, and result in undesirable sensor performance.

The only exception to this would be if a mechanical damping material were carefully designed and applied to help with the vibrational characteristics of the system. However, past experience

has shown that the use of mechanical damping materials, although desirable, is, at best, very difficult, when issues of temperature and durability requirements are considered.

3.14 Fasteners

The topic of fasteners and proper fastening techniques needs to be seriously evaluated and considered. Improper mounting characteristics can degrade what is an otherwise effective design for the structure/sensor interface.

Over the past several years, Delphi Delco Electronics has observed many incidents where the sensor mounting integrity resulted in deviations in predicted performance. Missing mounting bolts, loose bolts, and over-torque, have all lead to some form of sensor performance anomaly at one time or another.

Questions often come up regarding the use of weld nuts, u-bolts, clinch nuts, etc. The basic response to these questions is 'will the proposed mounting provide the appropriate torque and frequency performance for the life of the vehicle?' The choice of what materials to use is completely up to the customer, but the guidelines for the mounting integrity remain the same.

As we push for fewer and fewer mounting points, to simplify the assembly process and lower the cost, attention must be paid to further insure the reduced mounting complexity does not also reduce the reliability of the system. Care should be taken to insure that the assembly process has adequate checks and balances to control the installation of the sensors and avoid such common problems as missing fasteners, misalignment or under/over torque.

3.15 Corrosion resistance, life of mounting hardware

The specification for mounting hardware, particularly the crush zone sensors, must be able to withstand potentially severe environments and abuse conditions for the life of the vehicle, with virtually no degradation of load capacity or failures. The sensor system design assumes that the crash pulse characteristics of the vehicle will remain relatively constant over the life of the vehicle, and thus cannot correct for deviations due to the failure of mounting hardware such as bolts, weldnuts, j-clips, etc.

3.16 Hole pattern – no incorrect installation and assembly

This was touched on briefly in previous sections. But the important statement here is that all currently available sensor designs have a distinct sensitive axis orientation. Most devices are unidirectional with respect to the axis to be used for discrimination. If the sensor should not be

in this proper orientation, the sensing system will not perform as designed or expected. Even with electronic sensors, polarity is very important to the sensors response.

When planning the design for sensor locations, some thought should be given to a sensor footprint that will eliminate the chances of improper orientation during assembly. Also, each sensor on the vehicle should have a unique footprint, to avoid placing the wrong sensor/calibration in the wrong location. This is also important for future dealer service situations where the sensors could accidentally be installed incorrectly, resulting in degraded system performance. Usually connector keying (mechanical or electronic) will prevent this from happening, but every precaution should be taken to insure proper system performance throughout the life of the vehicle.

Insuring correct location and correct orientation can be accomplished with such features as offset holes, locator pins, interfering adjacent surfaces, etc.

4.0 Platform design/test guidelines

Many sensor design optimizations can be developed by manufacturing and test engineers. Each of the topics below relate to the impact of various assembly and test procedures which can affect the sensor performance or the crash data reliability. These will directly impact the calibration analyses performed at Delphi Delco Electronics.

4.1 Harness Routing

Earlier we discussed the connector location for a sensor, particularly in the crush zone. A number of possible failure modes have been experienced in the past due to the sensor wiring harness routing. First, it is possible in crush zone sensor applications to have the wire damaged before the sensor has been able to respond to a crash pulse. This could delay or eliminate a desired deployment of the safety system.

The recommendation is to take the time to design the sensing system with the impact of harness routing and sensor connector exit carefully evaluated for system performance optimization.

The sensor harness/wiring routing path should take the wires as far away from the exterior surface of the vehicle as possible. The routing should avoid sharp bends and pinch points, corrosive materials (battery acid), and moving mechanisms (belts, pulleys). The attachment of the wire harness to the structure throughout the length of the routing should include positive means of attachment such as rosebud or edgemetal clips.

The attachment clips should be sufficient to maintain the design intent routing of the harness, but the number of attachment points in the crush zone should be minimized to allow for some relative movement of the attachment points during a crash. Otherwise, this relative motion which occurs during vehicle crush could result in harness damage before the sensor has adequately performed its function. The goal is to prevent harness severing or grounding to the chassis for as long as possible, and to allow the sensor to complete its crash sensing function.

4.2 Manufacturability/assembly

When designing the sensor locations into the vehicle structure, the first priority is adequate sensing. But a strong second priority is to consider the final vehicle assembly and the manufacture of the components. For example, if the sensor is difficult to attach or requires blind access to mounting bolts, etc., this might lead to errors or incomplete installations, which ultimately could impact the effectiveness of the entire sensing system.

DFA/DFM techniques should be adhered to, but remembering that ultimately, the sensor performance will be the direct result of the quality and integrity of the attachment, and thus, a balance may need to be reached for optimizing both factors.

4.3 Flat/rigid mounting surface

We discussed flatness earlier, but it is important to express that for optimal sensor response, we must minimize off-axis (or cross-axis) vibrations where possible. This can be achieved in part by maintaining a flat interface between structure and sensor, so that the sensor will not 'rock' back and forth or pendulum during an event. This could create undesirable resonances and vibrations that could negatively impact sensor performance.

Additionally, stability can be obtained by using a rigid structural member for sensor mounting. Material thickness is one aspect of this. Depending on the sensor mass, the thickness of the material can be used to minimize localized instabilities.

In many cases though, cost and mass force us away from thicker materials, but significant gains have been made over the years with the use of 'ribs', doublers, and other localized stiffening techniques.

Remember, the goal is to maintain a frequency response of the system so it allows no amplification or attenuation of crash inputs below 500Hz or so. (1000Hz is desirable for crush zone sensors). So whatever techniques are used to provide the required structural stiffness, as long as they meet the performance goals, they will, in general, be acceptable.

4.4 Structure mount vs. bracket mount

The question of whether to mount the sensor directly to the structure or to a bracket which attaches to the structure has be raised many times. The generic rule of thumb is to minimize the number of mechanical transfer functions between the structure transmitting the crash pulse and the sensor reading the crash pulse. This would result in the recommendation of attaching directly to the structure. This is most desirable.

But since there are many factors to consider when designing a sensing system, there are reasons why a bracket might be used. For instance, if mounting on a floorpan, where flooding may be an issue, a properly stiffened bracket which raises the sensor off the floorpan, to reduce the chances of fluid submersion, would be desired. Again, the bracket must maintain the integrity of the crash pulse transmission.

Another example would be where the localized structure is not meeting the desired stiffness or flatness requirements. A properly designed sensor bracket could not only provide the appropriate orientation and flatness, but if designed adequately, could provide some localized stiffening to the structural member.

Remember that we must prevent undesirable resonances, cantilevers, and other mounting situations which might result in degraded sensor performance. Each sensing technology will also have its own sensitivities and characteristics that must be considered, such as mass, center of gravity, etc.

4.5 Longitudinal, lateral and vertical stability

The cross-axis sensitivities of a sensor design may demand even greater attention be paid to the mounting integrity. When a sensor, which is oriented in the longitudinal axis of sensitivity, is adversely impacted by signals which are experienced in the lateral or vertical axes, this results in what we call the cross-axis response of a sensor.

The sensor designs all have requirements for these sensitivities, however, they can and do exist. Care must be taken to insure that the vehicle/sensor interface and location selections are considering these cross-axis inputs.

Typically what occurs is the cross-axis inputs cause a desensitizing of the sensor. However, in one particular cantilevered design/mounting, the system resonance modes resulted in an 'increase' in the sensor sensitivity. Proper attention to the cross-axis response of this particular design would have minimized or eliminated this problem.

Each sensor technology and design will have its own unique characteristics and sensitivities. Therefore, it is not possible to give a generic guideline. Some sensors respond adversely to high frequency cross-axis inputs, while others are susceptible to low frequency cross-axis inputs. In general, mechanical designs have sensitivities at lower frequencies (<500Hz), while electronic designs may have sensitivities at higher frequencies (1000-2000Hz). The sensor supplier should know and understand these sensitivities and provide input to the customer for each technology as needed.

4.6 Minimal crash damage to sensor, harness, connector

Crush zone sensors are particularly sensitive to vehicle crash damage during a crash. Their location in the crush zone places them in danger of being damaged before they have completed their intended crash discrimination. See the discussions in section 3 for more information on this important topic.

In general, remember that the sensor needs to survive at least until the customer actuation goal time. Once the sensor has completed its discrimination, the information is latched in the central controller, and therefore, subsequent destruction of the sensor should not adversely impact the system performance.

4.7 Location of test accelerometers

There is a major push to eliminate crash testing in the development of crash safety systems, due to such factors as high cost, non-repeatability, and the significant loss of valid instrumentation data on many events. Eventually, Finite Element Modeling/Analysis (FEM/FEA) simulation techniques will be the method of system development. But until that time, both the crash sensor calibration activities and the validation of the new simulation techniques are very dependent on the reliability of the instrumentation data collected during crash events.

Also, it is very important to record the internal sensor signals whenever possible. The correlation between instrumentation accelerometers and the sensing device itself has been significant for resolving many product/vehicle/system issues. Verifying proper device performance in actual crash conditions is vital for complete characterization of the system.

Most crash sensor models are now 3D simulations. This means that they perform most accurately when fed the signals from the sensor location in the longitudinal, lateral and vertical axes. Thus, tri-axial accelerometers are virtually a requirement for all sensor locations. Recently, new designs of some crash sensing modules has led to the need to further study acceleration data which is rotated +/- 45 degrees from the longitudinal axis. Beyond this,

pressure sensors have been used by some suppliers in side impact door applications, and crush switches and 'crash damage' sensors are quickly becoming potential next generation devices. Out in the future, there is already a vision of radar or infrared forward anticipatory sensors that will interface with the crash discrimination system.

So the challenges for the test laboratories are clear. Adapting quickly and even anticipating the technological advances, to be able to provide crash data for these new systems, as well as continuing to improve the reliability and consistency of the current acceleration data.

Some guidelines for providing the best possible acceleration data for crash sensor simulation would be such items as placing the tri-axial accelerometer as close to the center of mass of the sensor as possible. Keeping the mass of the accelerometer pack low so it does not induce additional localized resonances and vibrations into the sensing system. Mounting the accelerometer in-line with the sensing elements sensitive axis will also help optimize the correlation between the simulation model and the actual performance of the sensor.

4.8 Tri-axial acceleration data

As stated in the last section, since most new sensor models are developed in 3D, the use of tri-axial data is useful and even critical for optimizing the calibration process. Since the cross-axis inputs, including gravitational effects, can influence the sensor performance, it is valuable to have the three axes of data as inputs to the simulation and calibration process.

This will help aid in the selection of not only calibration, but even choice of sensor technology to be used, based on the complete characterization of the structure.

5.0 Sensor design considerations

A number of vehicle/sensor interface concerns can be remedied at the sensor design level. Each of these areas can help to optimize the sensor response with minimal impact on the existing vehicle structures. Where possible, these techniques should be considered for the sensor applications of all vehicles.

5.1 3-point mounting

As mentioned earlier in this document, the concept of 3-point mounting actually refers to the idea that the sensor makes contact with the vehicle structure at multiple points. Especially with the new technology crush zone sensors, 3 actual mounting holes/bolts is not feasible. But even with one or two bolt designs, the sensor can still be made to contact the structure at other points besides the actual bolt locations.

The main point is to have the design controlled in 6 degrees of freedom. By maintaining tight controls over the DOF's, it is less difficult to calibrate a sensing system, and the system variability will also be better controlled. Specifically controlling the cross-axis conditions present at the sensor location will improve the sensing system performance.

5.2 Offset Holes

The use of offset hole patterns or locating pins serve 2 purposes. One purpose is to insure that the sensor is made to contact the structure at multiple points. Second, this concept provides for a more failsafe installation during the assembly process. Whenever possible, the sensor footprint should be such that the sensor can never be placed in an incorrect location or in the wrong orientation on the vehicle.

5.3 Cantilever brackets

This is a generic statement that really refers to mountings that do not adequately control the sensor stability. Cantilever brackets in particular, can result in large amplifications of resonant frequencies due to the center of mass of the sensor causing a 'diving board' effect at the structural member. Remember that under crash conditions, when the sensor is most important, there will be very high G's and any localized resonant phenomenon will be amplified dramatically.

In the worst case, if the resonance falls within the sensors most sensitive range of influence, these cross-axis inputs my directly impact the sensors discrimination capability. A stable mounting is critical for optimization of sensor performance.

5.4 Center of gravity mounting

With heavier sensor designs, the issue of center of gravity mounting becomes more crucial. The argument here is that the moment of inertia of the sensor may induce significant structural effects due to the pendulum effect of the sensor/vehicle interface. The heavier the design and the further away from the mounting plane that the center of gravity is, the more pronounced the effect on the structure. By centering mounting brackets or recessing the sensor inside the structure, such that the center of gravity is in the mounting plane, the more optimal the sensor performance and consistency will be.

The practice of center of gravity mounting is still true even for lower mass sensor technologies, but of course it is anticipated that the probability for performance deviations will be lower.

5.5 Low mass configurations

Another means for reducing the mass moment about the mounting plane is to simple reduce the sensor mass itself. Depending on the technology, there may be little that can be done. But as a general rule of thumb, it is desirable to used the lowest mass possible for a sensor design, to minimize the possible resonance effects under high frequency, high G conditions.

5.6 Design integrity

Several problems discovered over the years related back to the integrity of the sensor design. In older mechanical sensor designs, weld integrity was an issue. A bad weld joint could cause amplifications in resonance conditions and impact the sensor performance. In more recent designs, PC board/case interface properties, accelerometer stabilization on the PC board, and PC board resonances have all led to deviations in sensor performance.

Thus, as a general guideline, the sensing element in a sensor design should be carefully considered with respect to its mounting and stabilization within the sensing module itself. It is easy to look at the vehicle interface, but not enough attention is paid to how well the sensor module itself will transmit the signal to the sensing element. There is no logical reason that the transfer function of the sensing module case to the sensing element should not be adequately optimized for sensing. No gains, no attenuation and no frequency shifts should be present within the sensor design itself.

5.7 Resonances

Each sensor design can be vibration tested in the laboratory, and the resonances of the sensing element itself can be quantified. Simulation and adequately instrumented vibration/shock testing should be performed on all design proposals, to insure that the product will not introduce signals that are a concern for the particular sensor technology.

Obviously, sensor technologies will dictate what is acceptable or not, but there should be no conditions where the sensor design itself exposes the sensing element to undesirable conditions.

5.8 Vibration modes (direction)

The vibration modes or the direction of the vibration that result from the sensor design can be as significant as the frequency itself. Most sensors are not symmetrical, and therefore, the cross-axis sensitivities may be very different from the sensitivities in the sensors sensing axis. So when evaluating resonances of the structure or the sensing module, it is important to understand the sensitivities of the sensing element itself in a particular axis.

5.9 FEM, sine sweep, spectral analysis

Some of the techniques that can be used to quantify the sensor sensitivities include Finite Element Modeling of the design, vibration analysis through sine sweep and shock pulse testing, and spectral analysis of the collected instrumentation data.

The FEM is typically used early in the design phase to design aspects of the sensor module. The key is to expand these studies to look at the transfer function all the way through to the sensing element. This concept can help isolate weaknesses in the design and possibly provide low cost solutions early in the concept design phase. Ultimately product testing should be performed to evaluate the actual design performance and correlate these results to model predictions for future refinements to the FEM.

Laboratory vibration testing has proven very valuable in the sensing characterization process. With adequately instrumented sensors (do not forget to bring all critical sensor performance signals to the outside of the box for recording, such as the accelerometer itself, the safing signals, etc.), the sine sweep, sine dwell and shock pulse testing can quickly isolate a design or performance issue. This testing has not been used properly in the past. The only testing done was typically to look at mechanical durability, and not the system response during these conditions. This is changing as the designs become more sophisticated and the designers apply lessons learned.

The final link in the chain of design verification is the actual crash tests themselves. The data collected from the instrument grade accelerometers can be run through simulation models to correlate performance. Additionally, sensor signals should be recorded as well, for the purpose of correlation to the instrumentation results. Many performance problems have been resolved when the sensing unit was finally instrumented for recording internal signals. This should be considered very important during the early phases of a new product program.

Correlation between design, simulation, laboratory testing and vehicle testing is imperative to insure that the system is working as designed.

5.10 Sensor sensitivities

Throughout this document, we constantly have addressed the need to control the resonances in the sensing system to insure optimal sensor response. Section 7 will discuss the specific characteristics of each current sensor technology, but the point here is that each sensor is different and will likely require different application strategies. Thus, the knowledge of the desired sensor technology will be critical for truly optimizing the sensing system.

In general, as new or redesigned sensors become available for use, it will be important to extend the concepts of this document to incorporate the new product. The fundamentals will be the same, but the specifics of the technology may dictate a different course of action when optimizing the system.

5.11 Harness routing /location

On the vehicle side, we have discussed at length the issue of the wiring harness routing to avoid premature loss of sensor data. However, it is also important when designing a sensor that the same principles are applied such that there are different configurations and orientations of packaging, such that the customer has the opportunity to choose a package that minimizes the risks I this area.

So the sensor design must also consider these issues, and offer a solution that does not force the customer to non-optimal sensor packaging and placement with respect to the harness and connectors.

6.0 Case Studies

It is unfortunate, but sometimes mistakes or non-optimal solutions result and in most instances, these problems were not understood or identified until after production. The key is to learn from these experiences and incorporate these lessons into future designs. In the past 13 years since we began this latest generation of airbag system, we have learned many valuable lessons. These lessons will be covered generically here. We will not identify specific vehicles, sensors or programs, but will try to relate the important aspects of the experiences that relate to the sensitivities of the sensor design and vehicle interface.

6.1 SDM

A major joint effort to understand a field issue pointed out some very valuable lessons.

First, a sensor should always be subjected to testing while monitoring the internal signal output. In this case, an unknown PC Board vibration was causing very erratic signals at both the internal accelerometer and the internal mechanical arming sensor. By only monitoring the external instrumentation accelerations during development, none of these problems was observed.

Second, do not ignore problems experienced with ‘other’ sensor designs. In this same case, it turned out that a sister product had in fact experienced and identified this problem, but lack of proper communication and sensitivity led to not exploring this issue and subsequently finding it out after 2 years of production.

Third, if you see something that does not quite correlate with simulations or expected performance, regardless of how trivial, do not take it lightly. All anomalous behavior should be subjected to immediate 5 phase corrective action assessments. It turned out that we had experienced some minor performance deviations that were blamed on test method or other circumstances, when in fact, a detailed analysis might have provided early warning that a problem existed in the design.

In general, it must be understood that all sensor designs have an absolute requirement for accurate transmissibility of the crash signal to the sensing element, without corruption. This MUST be insured via adequate design and testing.

6.2 Electromechanical Sensors

Since 1974, electromechanical sensors supplied by Delphi Delco Electronics have been used for vehicle airbag systems. In the interim years, we have used Breed Ball-in-tube, Nippondenso rotary-spring-mass, Hamlin reed switch, Schmitt G-switch and other E/M devices. Each of these devices has its unique sensing characteristics, and therefore, unique weaknesses. Similar to the discussion with SDM above, the important factor is to understand the design limitations, insure adequate testing of the design, and fully comprehend the vehicle environment where the sensor will be located.

One particular device exhibited some characteristics that were observed but unfortunately, the implications of these characteristics were not fully evaluated. It turns out that under severe cross-axis environments, the device can either actuate when not desired, or actuate later than desired. This dichotomy results in a difficult situation. As the corrective action to one problem may result in enhanced problems with the other characteristic.

In the end, it was clear that this particular device was not suited to crush zone sensing. Testing during the development of this device gave early indications of problems, but there was not enough focus on root cause corrective action, due to so many other new products being introduced simultaneously.

Eventually, a nearly 2 year study was completed on these performance anomalies. The end result was that the simulation model could not adequately characterize the device under some conditions, and therefore, we could not anticipate what might happen under all circumstances. This 'gray' area of performance led to the conclusion that the device was not desirable for this type of application, unless significant vehicle testing were performed.

There are other similar stories regarding electromechanical devices. It is very difficult to have an accurate simulation of the complex physics of such a device, and therefore, the actual performance during crash conditions can deviate from the predictions. The amount of deviation will dictate whether or not a device is acceptable to use in a given application.

Keep in mind again that each device is different, and what may work well in one vehicle environment, may work quite poorly in another vehicle environment. If the actual testing of the device shows some areas of concern, it must be taken seriously. The root cause of the problem

needs to be resolved, if possible, and certainly, if performance problems can not be adequately explained, it is wise to re-consider whether this device is the proper solution for this application.

Development testing usually will give clues to potential problems, the key is to take advantage of these clues and not pass them off as a 'fluke' or a bad test, unless subsequent, detailed analysis of the situation convinces everyone that it truly was a test problem. Remember that these unusual behaviors during testing are generally a hint at something much bigger.

6.3 Electronic Satellite Sensors

These devices are new technology within the last 3 years or so. The push for smart sensors and side impact airbags has driven a new, high tech solution. However, placing a micromachined accelerometer in the severe crush zone environment must be done with utmost care and attention to design details. It is early in these programs, but already, many valuable lessons have been learned.

And once again, these lessons came after we had seen warnings from test conditions that went unresolved. The testing was telling us something, but we chose to consider that it was improper test setup or vehicle conditions, and not take a hard look at the root cause.

The scenario is that a series of tests is completed with the accelerometer output from our device being recorded. We are smart enough now to learn from past experience on the SDM. We used instrumented devices for early testing to verify performance. Both internal and external testing are completed. The internal testing goes smoothly and the device looks great. However, in early vehicle testing, we see anomalies in the output signal. Comparing these to the instrumentation data, it is clear that there is a problem.

We question the test setup and instrumentation at the OEM. Our internal testing never showed anything like this, and it is clear to us that they must not be properly instrumenting our device. It is passed off as something that will be corrected by the OEM. Until the next data comes in from a different OEM with similar response… and then another OEM…

But by now, 6-8months has gone by, and even with the more aggressive test plan, we have ignored an important piece of data. This would later turn out to be the result of testing in actual vehicle crash environments. In the presence of the very high G, high frequency conditions (which are not actually collected in the instrumentation data, but are generally filtered out) experienced in the vehicle crashes, the device exhibits an undesirable response.

Another reminder that even if you do more aggressive testing, you must take all input data seriously. The root cause of every deviation in performance must be quantified and understood. Corrective actions must be taken. Adequate testing is only a benefit if you act on the results.

This is true for all sensor types both discussed here and those that will come on board in the future.

7.0 Revision Record

Reason for Revision	Date of Revision	Person Responsible
Initial Release	1/15/91	Chris Caruso
Updated to current technologies	11/1/99	Chris Caruso
Removed CONFIDENTIAL label for Toyota	8/14/00	Chris Caruso